Turbocharger design and optimization by adjoint method coupled with CHT analysis

TURBOCHARGER DESIGN AND OPTIMIZATION BY ADJOINT METHOD COUPLED WITH CHT ANALYSIS

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Abstract

The design of turbochargers for modern automotive applications requires the solution of a highly constrained problem in which targets of extended operative range and performance are coupled with the need of improved synergies with surrounding engine subsystems. The optimization of Variable Geometry Turbines (VGT) demands a multidisciplinary and multipoint approach aimed at improving the machine efficiency while complying with the restrictions imposed by the wide thermal spectrum experienced during various driving conditions.

Conjugate Heat Transfer (CHT) describes the process of thermal interaction between a solid body and its surrounding fluid. The numerical simulation of CHT involves the simultaneous solution of both domains in a closely coupled manner. The implementation of this analysis in industrial optimization processes is usually not undertaken due to its computational cost.

The present PhD program focuses on the application of CHT analysis to the optimization of VGT turbochargers by introduction of thermal evaluations in an adjoint-based shape optimization framework. The goal is to demonstrate the possibility of enhancing the system efficiency by improving the effectiveness of the optimizer in its design choices thanks to the increased fidelity in performance prediction, the reduction of current safety margins on applied constraints and the minimization of heat losses.

Gradient based optimization methods - if using the adjoint method to compute sensitivities - have a clear advantage over gradient-free techniques (e.g. Evolutionary Algorithms) because allowing a faster identification of the optimum of an objective function. Moreover, adjoint methods result in less computationally expensive evaluations of the sensitivity of the objective function with respect to variations of the control parameters by decoupling of the gradients calculation through the state equation. Therefore this methodology offers a suitable optimization framework for the implementation of high-fidelity analyses such as CHT, especially when considering rich design spaces.

The development of the procedure is approached through several steps. A heat transfer solver is first generated and radiation term is included to evaluate the large heat dissipation occurring through the turbine scroll. A Fluid-Structure Interface is then designed in order to transfer temperature and heat fluxes information between the fluid and solid domains and to deal with interpolation issues between the two regions. A Conjugate Heat Transfer computation is then implemented using the partitioned hFFB method. The discrete adjoint formulation is applied to the problem and automatic differentiation techniques are introduced for gradients calculation. Finally an adjoint one-shot method is investigated in order to reveal the possibility of reducing the computational cost of the evaluation process in favor of an anticipated introduction of CHT analysis during the optimization.

The design of VGT turbochargers is approached by studying the stator-rotor interactions through implementation of a mixing plane. The highly perturbed flow field generated at totally closed VGT vanes position is examined by introduction of stabilization techniques and their influence on the optimizer effectiveness is analyzed. Finally the CHT analysis is tested in several operative conditions, with focus on its application to the turbine scroll and vanes channel.

Keywords: Adjoint methods, Conjugate Heat Transfer, Turbocharger optimization, Variable Geometry Turbine